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Biological Maturity Associated Variance in Peak Power Output and Momentum in Academy Rugby Union Players.

Abstract

Purpose: The study aimed to evaluate the mediating effect of biological maturation on anthropometrical measurements, performance indicators and subsequent selection in a group of academy rugby union players.

Methods: 51 male players 14-17 years of age were assessed for Height, weight, and BMI and percentage of predicted mature status attained at the time of observation was used as an indicator of maturity status. Following this, initial sprint velocity (ISV), wattbike peak power output (PPO) and initial sprint momentum (ISM) was assessed.

Results: A bias towards on-time ($n = 44$) and early ($n = 7$) maturers was evident in the total sample and magnified with age cohort. Relative to UK reference values, weight and height were above the 90th and 75th centiles, respectively. Significant ($P \leq .01$) correlations were observed between maturity status and BMI ($r = .48$), weight ($r = .63$) and height ($r = .48$). Regression analysis (controlling for age) revealed that maturity status and height explained 68% of ISM variance; however, including BMI in the model attenuated the influence of maturity status below statistical significance ($p=.72$). Height and BMI explained 51% of PPO variance, while no initial significant predictors were identified for ISV.

Conclusion: Results indicate a clear selection bias towards earlier maturers within this sample of rugby union players. This was attributable in part, to the mediating effect of maturation on body size, which, in turn, predicted performance variables.

Keywords: *Percentage of mature height, maturation, growth, rugby, adolescence, momentum*

Introduction

Many factors influence talent identification and development. The process of identifying and developing talented young rugby players generally starts in adolescence. As such, elite premiership clubs invest significant amounts of capital funding in academy programmes in order to target the various facets of talent identification with an ambition to ensure the best talent is identified, nurtured and developed for performance on the elite stage. One such consideration of talent identification which has attracted ample attention in recent years is the influence of individual differences in biological maturation among youth players (Malina, 2011). These differences are likely to have a mediating role in anthropometry, and by inference resulting performance and thus talent development. This variation may also influence practitioners' perceptions of ability and potential.

Biological maturation is a process marking progress towards the mature (adult) state. Adolescents of the same chronological age, vary greatly in maturity status (e.g. Malina, 2011). Variation in maturity status has physical and psychological implications, which may impact the processes of talent identification and development in sport. For example, males who are advanced in biological maturation are more likely to be represented in sports that demand greater size, speed, or strength, and increasingly so with age and competitive level (Malina, Eisenmann, Cumming, Ribeiro, & Aroso, 2004b).

Maturation can be conceptualised and quantified in terms of status, tempo and timing (Baxter-Jones, Eisenmann & Sherar, 2005; Malina, Bouchard & Bar-Or, 2004a). Status refers to the attained level of maturation at the time of observation. Timing refers to the age at which specific maturity-related events occur (e.g., ages at menarche and peak height velocity), while tempo refers to the rate at which maturation progresses (Malina et al., 2004a). The process occurs in several independent, yet correlated, biological systems including the skeletal, dental, reproductive and neuroendocrine systems (Malina et al., 2004a; Cumming, Sherar, Pindus, Coelho e Silva & Malina, 2012).

The greater prevalence of early maturing males in sport has been attributed to a number of factors, including more suitable/favourable anthropometric/morphological attributes, superior functional capacities, preferential treatment, more access to learning resources and opportunity to train and compete (Malina, Rogol, Cumming, e Silva, & Figueiredo, 2015). Variance in these groups can be huge due to these biological differences. Early maturing males are generally taller and heavier than their peers from the age of eight onwards (Malina et al., 2004a), though maturity associated differences in functional capacity (i.e., speed, strength, power), around 11 to 12 years. The physical and functional advantages associated with early maturation in males suggest that these individuals may be more likely to be identified earlier, assigned important roles/positions, receive greater encouragement and reinforcement for participation, hold more positive perceptions of self, and receive greater access to specialized coaching and/or training resources (Malina, Rogol, Cumming, e Silva, & Figueiredo, 2015).

While advanced maturation in males affords an athletic advantage in adolescence, many of the physical and functional benefits associated with early maturation are transient (Lefevre, Beunen, Steens, Claessens & Renson, 1990), with late maturing males catching up, and often surpassing their early maturing counterparts in adulthood (Pearson, Naughton & Torode, 2006). This prevalence of late maturers “catching-up” is more apparent in height than in weight (Malina et al., 2004a), and has been documented in game sports such as soccer (Malina, Coelho e Silva & Figueiredo, 2013). However its important to note that this “catch-up” in youth athletes is biased to some extent by the selectivity of sport and differential drop-out/exclusion.

Unfortunately, those involved in the development of young athletes are often required to make decisions relative to selection, funding, and retention during the period over which large inter-individual differences in biological maturity are observed, and prior to catch-up growth which occurs in late adolescence. Thus, such late maturing males are judged on attributes that will not be fully realized until young adulthood (Till, Cobley, O’Hara, Chapman & Cooke,

2013). The implications of such bias are illustrated in Lefevre et al. (1990) who demonstrated that later maturing boys demonstrated superior performances on tests of limb movement speed and explosive and static strength as adults.

Research addressing the impact of variation in biological maturation upon performance and selection in youth rugby is limited and largely restricted to Rugby League. Rugby emphasises size, speed, strength, and power. Speed is considered a highly valuable component of performance success in rugby union (Duthie, Pyne, Marsh & Hooper, 2006). Among professional players, speed over 10 and 20 meters has low-to-moderate correlations with the number of line breaks, tackle breaks, meters advanced, and tries scored (Smart, Hopkins, Quarrie & Gill, 2014). Power as a predictor of tackle ability is also considered an important performance indicator in rugby. Of relevance, maximal power and momentum (a function of mass and speed) distinguished between first and second division rugby league players (Baker & Newton, 2008). Given the importance of speed and power for match performance, it may be argued that a bias in favour of those who are advanced in maturation would be especially pronounced in elite rugby union academies.

Study aims:

- (1) Describe the estimated maturity status and anthropometrical characteristics in a selection of youth academy rugby players
- (2) Examine the contribution of maturity status to anthropometrical characteristics and subsequent performance on tests of momentum, speed, and peak power output in premiership elite youth rugby players.

Methods

Design and Participants

The study adopted a cross-sectional correlational design. Participants were male ($N = 51$) British rugby academy players 14-17 years (15.9 ± 0.7 years) from a premiership club in the south west of England. Ethical approval for the study was obtained from the University

Research Ethics Committee. Written consent to participate in this study was obtained from the Academy head via *loco parentis*. Parents were informed of the research by email, and asked to provide passive consent (i.e. contact the school/researchers if they did not wish their child to take part). Verbal assent was also obtained from subjects prior to testing.

Anthropometry

All measurements were taken by a single observer using standardised procedures (Malina, 1995). Height was measured using a portable stadiometer (Road Rod 214, Seca Ltd.) to the nearest 0.1 cm. The inter- and intra-observer technical errors of measurement (Perini, Oliveira, Ornellas & Oliveira, 2005) for height were 0.17 cm. and 0.05 cm, respectively. Measurements were conducted with a separate sample to assess reliability estimates. Body mass was assessed to the nearest 0.1 kg using an electronic scale (Omega 783, Seca Ltd.) with participants wearing a lightweight rugby training shirt with rugby shorts only (no prior exercise was performed during the day). The body mass index (BMI; kg/m^2) was calculated.

Maturity status

Prior to testing all parents provided self-reported measures of biological maternal and paternal height. Percentage of predicted mature (adult) height attained at the time of observation was used as a non-invasive estimate of maturity status. The method assumes that an individual who is closer to his predicted adult height than expected for age is advanced in maturity status, with the converse being true for delayed maturity status (Malina et al., 2004a). The Khamis-Roche method (Khamis & Roche, 1995) was used to predict adult height from current age, height and weight of the player and midparent height (mean of self-reported heights of biological parents). Self-reported parental heights were adjusted for a tendency towards overestimation using equations constructed from over 1000 measured and estimated heights of adults (Epstein, Valoski, Kalarchian & McCurley, 1995). Percentage of predicted mature height has been validated relative to skeletal age in youth American footballers (Malina, Dompier, Powell, Barron & Moore, 2007). It has also been used in studies of British youth (Cumming et al., 2011). This median error bounds between actual and predicted mature height from 14 to 17 years of age in males ranged from 2.8 to 0.8 cm (Malina, e Silva,

Figueiredo, Carling & Beunen, 2012). Estimated maturity status was expressed as a z-score, using the percentage of predicted adult height attained at the time of measurement, and half yearly age and sex-specific means and standard deviations from the Berkley Guidance Study (Bayer & Bayley, 1959). The criteria for identifying players as late, on-time, and early based on z-scores was as follows; late < -1 , on time > -1 & < 1 , early ≥ 1 .

Protocol

After measuring height and weight, performances on three standard tasks were measured using standard testing procedures. Participants were familiar with the protocols. Tests were administered in the following order with 30 minutes of rest between tests:

(1) *Peak Power Output (PPO)*: Participants performed a maximal Watt Bike Pro (WPC Model B, Wattbike Ltd.) effort at a resistance level of five, for 6 seconds (s) following 10 s of cycling at 30rpm. This was repeated 3 times with 30 s of recovery between each attempt. The highest value (watts) of the 3 attempts was recorded. This particular test is commonly utilised in premiership rugby academies as an indicator of peak power (M. Atkinson, personal communication, 10 November 2015.).

(2) *Initial Sprint Velocity (ISV) and Initial Sprint Momentum (ISM)*: Photocell light gates (TC-System, Brower Ltd.) were set up at 8 meters (m) and 12 m (with an 8 meter run up). After an intensive warm-up, subjects performed 3 sprints running past a 15 m mark. Individual sprints were recorded between 8-12 m. Velocity was calculated as $1/(\text{sprint time}/4)$ yielding $\text{m}\cdot\text{s}^{-1}$ over 8-12 m. Three trials were given with 45 s rest between trials. The mean the three trials was used for analysis (intra-class correlation of .83 ($p < .001$)). The rationale for sprint velocity between 8 to 12 m was as follows. Although peak sprints in elite rugby players occur between 30-40 m (Barr et al., 2013), research with premiership rugby players indicates that players in only 4 of the 15 positions covered any distance at peak sprint speed (Cahill, Lamb, Worsfold, Headey & Murray, 2013). In rugby union, contact or line breaks usually occur at the onset of breaching the gain line, which in set piece play (from scrums, line outs, rucks) is 10 m from the initial line of attack. As a result, sprint velocity at this point is of most

relevance. The light gates were set up between 8-12 m in order to improve reliability of measures taking into account the possibility of limb movements breaking light barriers prior to the subject's centre of mass. ISM was then calculated by multiplying ISV by the subject's weight (kg). Momentum was chosen as a performance variable as it has significantly discriminated between different divisions of rugby players (Baker & Newton, 2008). This protocol is similar to that of Barr, Sheppard, Gabbett & Newton (2014) investigating sprint momentum in elite rugby players.

Analysis

Descriptive statistics for four single year age groups were calculated for chronological age, height, weight, BMI, maturity status and performance variables (ISV, ISM, PPO). Mean height values will be compared with UK reference value centiles (Freeman et al., 1995). Pearson product-moment correlations (one-tailed) were conducted to examine the direction and magnitude of relations between the variables of interest. Multiple hierarchical linear regressions were used to examine the main effects of age, height, BMI (as an indicator of mass for height), and maturity status on the 3 performance variables (controlling for age). To control for age, this variable was entered in the first step of the model. Weight was excluded from regression models as it is highly correlated with the BMI. Collinearity among predictor variables can amplify standard errors associated with the regression parameters yielding difficulty in achieving significance and thus interpreting results.

Results

Descriptive statistics are summarized in Table 1 by chronological age group. Height, weight, BMI, z-scores and percentage of attained adult height increase, on average, with age. Mean weights of 14-16 year old players fall between the 90-97th centiles of UK reference values (Freeman et al., 1995), while mean heights fall between the 75-90th centiles of the reference; means for 17 year olds exceeded the 97th centile for weight and the 90th centile for height. Mean values for PPO and ISM demonstrate a trend towards increasing with age group, but ISV appears to show minimal variance across age groups.

TABLE GOES HERE – TABLE 1

Pearson product-moment correlations (one-tailed) among variables of interest are shown in Table 2. Maturity status (z-scores) is a significant correlate of age, height, weight and BMI. Maturity status correlated positively and with and PPO and ISM. The associations were statistically significant and moderate-to-large in magnitude (Small, $r = .1$; Moderate, $r = .3$; Large, $r = .5$) as classified by Hopkins, Marshall, Batterham and Hanin (2009). Particularly relevant correlations include the large correlation observed between weight and z-score ($r = .63$), between ISM and z-score ($r = .56$), the moderate-large correlation observed between z-score and PPO ($r = .46$) and weights moderate negative correlation with ISV ($r = -.24$).

TABLE GOES HERE – TABLE 2

Results of the multiple hierarchical linear regressions are summarized in Tables 3-4. Age was entered into each of the models as the first variable BMI was excluded from the hierarchical model for predictors of ISM (Table 3) to minimise multicollinearity as BMI and momentum are both by-products of weight. The final regression model predicting ISM is significant and explains 68% of the variance (Table 3). Maturity status and height are significant moderate positive predictors of momentum. The hierarchical regression model predicting PPO is also significant and explains 51% of the variance (Table 4). Both height and BMI are significant moderate-large positive predictors of power output. The hierarchical regression model predicting ISV is not statistically significant ($F = 1.08$, $R^2 = .09$, $p = .37$).

TABLES GOES HERE – TABLE 3 & 4

Discussion

As previously noted, recent literature investigating the influence of biological maturation and its influence on anthropometry, selection and performance indicates a clear selection bias toward early maturing individuals within a variety of sports including rugby league. However this phenomenon has not been investigated within the domain of rugby union. As such this study aimed to Describe the estimated maturity status and anthropometrical characteristics in a selection of youth academy rugby players. Following this, the current study aimed to examine the contribution of maturity status to anthropometrical characteristics and subsequent performance on tests of momentum, speed, and peak power output in premierships elite youth rugby players.

The results suggested a selection bias towards on-time or early maturing males in youth rugby, of the total sample, 7 individuals were classed as early maturers and the remaining 44 as on time with no late maturers identified. The maturity-related bias also increased with age, as evidenced in the positive correlation between maturity status and age. This trend may reflect the more competitive and/or physical nature of the game with increasing chronological age group, e.g. greater defence structure yielding more contact, and/or a greater disparity in body size and functional attributes. The observed bias was consistent with studies of youth rugby league players (Till et al., 2011) and also other youth sports (Malina, 2011; Malina, Cumming, Morano, Barron & Miller, 2005). The results were consistent with the general assumption that advanced maturation affords an athletic advantage in youth rugby, and contributes towards the selection and exclusion of young players, both formally and informally.

Success in rugby is influenced by a range of physical and biomechanical factors, many of which are, in turn, impacted by body size (Norton & Olds, 1996). In addition to being

advanced in maturation, players in the current study were taller and heavier, and carried greater mass for stature than the general population of youth as evidenced in their size relative to UK reference values. Previous research within rugby union has documented that a larger body size is associated with superior scrummage performance (Quarrie & Wilson, 2000) and competitive success within rugby league (Gabbett, Kelly, Ralph & Driscoll, 2009) which likely explains the sample skew towards individuals of greater body size within this academy sample.

Maturity status was a positive correlate of body size which is consistent with studies of youth athletes in soccer (Figueiredo, Coelho e Silva, Cumming & Malina, 2010).

The results were also consistent with the observation that maturation was more strongly related to anthropometric dimensions than specific measures of functional capacity among adolescent rugby players (Till et al., 2011).

Favourable anthropometry as in increased body mass may also provide a direct competitive advantage in rugby-specific technical components, e.g., in lowering the centre of gravity and widening the base of support in rucks and scrums to increase stability (McKenzie, Holmyard & Docherty, 1989). Given that mass positively influences stability, a larger body mass will presumably benefit this practice. Other aspects of performance, however, may not be influenced in such an unequivocal fashion. Body mass per se does not appear to be the sole determinant of tackling success; rather momentum, a function of mass and speed, appears to be critical (Hendricks, Karpul & Lambert, 2014).

Initial Sprint Momentum and Velocity

The regression models examining the contribution of individual differences in growth and maturation to initial sprint momentum (ISM) and velocity (ISV) were of particular interest. Maturity status and height were positive and significant predictors of momentum (Table 3). As momentum is a function of mass and speed and maturity status was unrelated to velocity (Table 2), it is reasonable to assume that the positive impact of maturity status on ISM was largely due to greater mass. Consistent with this contention, the effects of maturity

status on ISM were attenuated and non-significant when BMI was included in the regression model. Given that advanced maturation in males is associated with greater gains in absolute and relative fat-free mass (Malina et al., 2004a), it was not surprising that advanced maturation was also associated with greater ISM. This conjecture was also consistent with previous rugby research; differences in momentum favouring senior over junior players were the result of increases in body mass at similar levels of speed (Barr et al., 2014). Similar observations were also noted in comparisons of momentum and body mass in first versus second division rugby league players (Baker & Newton, 2008).

Maturity status was not correlated with ISV, and the regression model predicting individual differences in initial sprint velocity failed to explain a significant amount of variance attributable to maturity ($B = -.05$, $SE = .23$, $\beta = -.04$, $p = .78$). While the results suggested that advanced maturation did not afford an advantage in terms of ISV, they equally implied that it was not a disadvantage. Speed requires the ability to develop mass-specific forces in a brief period of time (Scholz, Bobbert & van Soest, 2006); however, higher body mass may negate the ability to develop these mass specific forces (Weyand, Sandell, Prime & Bundle, 2010). The correlation between body mass and ISV in the sample of youth rugby players was indeed negative (Table 2). Accordingly, it may be argued that the greater mass associated with advanced maturity status could potentially attenuate the velocity component of momentum, resulting in inferior performance. However, more mature players showed increases in weight and ISM without compromising on ISV (Table 2).

The lack of an association between maturity status and ISV in youth rugby union players contrasts observations in youth soccer (Malina, Eisenmann, Cumming, Ribeiro & Aroso, 2004b), handball (Matthys, Vaeyens, Coelho e Silva, Lenoir & Philippaerts, 2012) and basketball (Torres-Unda et al., 2013) players. This may be related to the nature of the test and/or the specific demands of rugby union. Several studies in both rugby league and union have also noted no variation between playing classes with regard to 10-meter sprint speed times (Baker & Newton, 2008; Barr et al., 2014). It is also possible that while advanced

maturation contributes to speed over longer distances (e.g., 30m) in contrast to shorter distances as used in the present study.

Although research regarding momentum within rugby union is currently limited, the findings in the current study suggest that advanced maturity is associated with superior momentum, but not speed. Momentum may be more important to performance in rugby than speed. For example, the number of tackle breaks usually favours the winning side in rugby union (Ortega, Villarejo & Palao, 2009); tackle breaks often achieved through dominating contact with momentum (Wheeler & Sayers, 2009). In the similar code of rugby league, momentum more consistently discriminated between classes of player than speed (Baker & Newton, 2008).

Peak Power Output

Height and BMI, but not maturity status, were positive predictors of PPO (Table 4). While maturity status was positively correlated with PPO, the results of the regression model suggested that much of this association operated through greater stature and BMI. Nevertheless, future studies should examine the extent to which differences in body size and composition may mediate relationships between maturity status and PPO in rugby players. PPO successfully discriminated rugby players of different playing abilities (Baker & Newton, 2008). Similarly, the vertical jump test has also discriminated between playing ability in rugby league (Gabbett, 2002).

Limitations

This study has several limitations. In addition to a relatively small sample, the method used to estimate maturity status was developed on U.S. youth. Although U.K and U.S growth charts are similar, further research is required to determine the reliability of the adult height prediction equation and subsequent conversion to z-scores with British youth. There is also a need to validate the maturity indicator relative to clinically established indicators (e.g., skeletal age, stage of puberty) in youth rugby players. Additionally, no reliability estimates were calculated for PPO. Future studies should assess this to improve the reliability of methods employed when using Wattbike PPO as an indicator of power output.

The study was also limited to a single rugby club, which may not be representative of elite rugby academies as a whole. Future research should aim to further investigate the prevalence of selection bias drawing on samples from a variety of elite academy setups to gain a more comprehensive and balanced understanding. It is also imperative that future research consider other components of performance including skill based technical abilities, psychological and qualitative factors to further understand the extent to which maturity status influences performance in rugby union beyond that of physical characteristics. In order to determine more robust conclusions regarding the influence of maturation on selection and performance in elite youth rugby, similar studies should be carried out and ideally with even more participants.

Practical application(s)

Given the transient nature of size and functional differences associated with variation in biological maturity status among adolescent boys (Lefevre et al., 1990), care should be taken not to discriminate based on maturity-mediated advantages in functional performance. It is likely that exceptional talent is lost through (de)selection based upon the lacking physical attributes of late compared with early maturers who perform better on snap shot assessments currently utilised by elite rugby academies (Till et al., 2013). Such individuals, if retained and nurtured, may surpass that of early maturing counterparts (Lefevre et al., 1990). Elite rugby setups should consider biological maturity when evaluating and developing young players. One way in which this may be achieved is through creating training and playing divisions based on size in a process known as ‘bio-banding’ or by maturity status, coined ‘maturity-matching’ (Malina et al., 2004a). Yet a noted limitation of such methods are that they fail to consider qualitative factors and psychological factors that accompany cognitive development throughout maturation (Brown et al., 2012). Practitioners might also consider the development of performance standards that account for the contributions of potential confounding factors such as maturation and/or relative age. Practitioners, should also consider how individual differences in maturation might inform the prescription of strength and

conditioning programmes, with the purpose of optimising development and minimizing injury risk.

Conclusion

The results of the current study are consistent with previous literature in other sporting domains, displaying a clear, evident, selection bias towards earlier maturing male. This prevalence appears to result from the superior anthropometric attributes exhibited, which likely contributed towards improved components of speed, anaerobic power and momentum. Such components likely translate into improvements in functional capacity which are paramount to success within the sport and subsequently, dictate selection. Although not investigated within this study, it is likely that coinciding maturity-mediated qualitative developments (e.g. hormone circulation and neural progression), further contributed towards functional performance. As such, future research should aim to investigate these mechanisms to gain a more rounded appreciation of maturations influence on sport performance. The selection bias associated with earlier maturers will likely be amplified in rugby union when compared with other sports due to the physical nature of the game. As such, elite rugby academies should take the transient influence of maturity into account when evaluating and comparing individuals within their academy setup, to maximise initial talent investment.

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Table 1. Mean values for chronological age, anthropometric measurements, percentage of peak adult stature attained at measurement, individual z-scores as well as performance variable measurements according to age cohort

	Mean \pm s			
	14 Year Olds (n = 5)	15 Year Olds (n = 19)	16 Year Olds (n = 23)	17 Year Olds (n = 4)
Age (years)	14.6 \pm 0.3	15.5 \pm 0.4	16.3 \pm 0.2	17.4 \pm 0.4
Height (cm)	172.3 \pm 4.4	176.9 \pm 4.5	180.6 \pm 8.2	184.9 \pm 1.6
Weight (kg)	66.0 \pm 13.6	75.6 \pm 8.5	81.6 \pm 13.4	88.6 \pm 9.3
BMI (kg \cdot m ⁻²)	22.1 \pm 3.7	24.1 \pm 2.1	25.0 \pm 3.7	25.9 \pm 2.7
%PAS	95.5 \pm 1.6	97.4 \pm 1.6	99.1 \pm 0.9	100.1 \pm 0.4
z-score	.50 \pm .45	.50 \pm .34	.65 \pm .35	.92 \pm .23
PPO (watts)	1054 \pm 263	1208 \pm 193	1242 \pm 166	1442.8 \pm 41.1
ISV (m.s ⁻¹)	6.7 \pm 0.38	7.01 \pm 0.47	6.93 \pm 0.43	6.90 \pm 0.58
ISM (kg.m.s ⁻¹)	446.1 \pm 113.8	529.1 \pm 59.88	562.5 \pm 75.3	609.2 \pm 56.68

Note: Age = chronological decimal age; BMI = body mass index; %PAS = percentage attained of predicted adult stature; PPO = peak power output; ISV = initial sprint velocity; ISM = initial sprint momentum; z-score = maturity status.

Table 2. Pearson product-moment correlations (one-tailed) between measures of chronological age, predicted adult stature, percentage of predicted adult stature attained, maturity status, anthropometry and performance variables

	1	2	3	4	5	6	7	8	9
1. Age									
2. Height	.48**								
3. Weight	.42**	.60**							
4. BMI	.25*	.16	.88**						
5. PAS	.13	.88**	.38**	-.05					
6. %PAS	.78**	.54**	.60**	.43**	.09				
7. z-score	.32*	.48**	.63**	.48**	.16	.75**			
8. PPO	.36**	.57**	.67**	.51**	.43**	.45**	.46**		
9. ISV	.07	-.13	-.24*	-.20	-.17	.10	-.15	.04	
10. ISM	.46**	.56**	.91**	.80**	.33**	.64**	.56**	.67**	.18

Note: Age = chronological decimal age; BMI = body mass index; PAS = predicted adult stature; %PAS = percentage attained of predicted adult stature; z-score = maturity status; PPO = peak power output; ISV = initial sprint velocity; ISM = initial sprint momentum. ** Correlation is significant at the 0.01 level (1-tailed). * Correlation is significant at 0.05 level (1-tailed).

Table 3. Final model hierarchical multiple regression analysis on predictors of initial sprint momentum (ISM) with F values and estimated R^2 after adjustments for age

Variable	B Unstandardized	$SE\ B$	β Standardised
Age	22.93	13.54	.21
Height	3.46	1.54	.30*
z -score	77.85	27.73	.35**
R^2		.68	
F		13.11**	

Note: Curve estimation yield between ISM and z -score (Linear $F = 21.83^{**}$), height (Linear $F = 22.58^{**}$).

** Significant at the 0.01 level. *Significant at the 0.05 level.

Table 4. Final model hierarchical multiple regression analysis on predictors of peak power output (PPO) with F values and estimated R^2 after adjustments for age

Variable	B Unstandardized	$SE\ B$	β Standardised
Age	2.57	31.68	.01
BMI	26.04	7.36	.42**
Height	13.72	3.61	.49**
z-score	12.25	72.03	.02
R^2		.51	
F		12.02**	

Note: Curve estimation yield between PPO and z-score (Linear $F = 13.39$), height (Linear $F = 23.69^{**}$), BMI (Linear $F = 17.58^{**}$).

** Significant at the 0.01 level. *Significant at the 0.05 level.

